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CORNING

Emerging LD Engine Technologies

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April 13, 2018
ARPA-E NEXTCAR 2018
Southfield, MI

[(1)] ICCT White Paper, March 2017
[(2)] TAR MTE – EPA, NHTSA, CARB, July 2016
[(3)] ICCT, Technical Brief, July 2015
[(4)] Mazda, Aug 2017

Nissan Infiniti: 3.7L V6 → 2.0L I4 VC-Turbo

2019 Chevy Silverado 5.3L & 6.2L V-8s

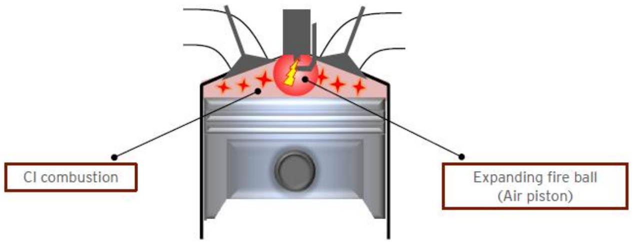
37 mpg on demo F-150 truck: 2.7L 3-cyl opp. piston

Mazda SPCCI engine

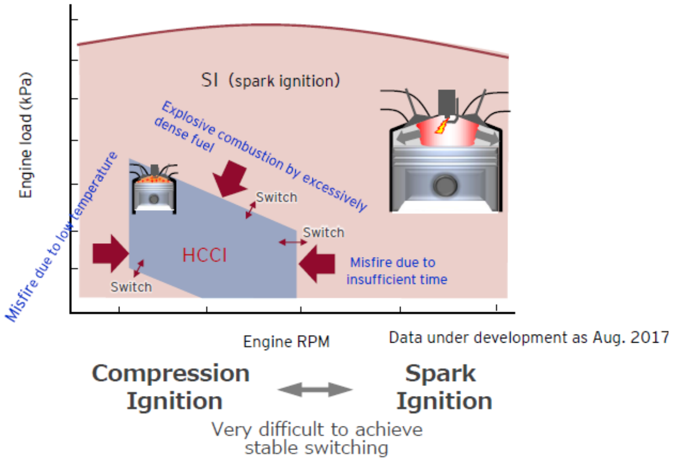
	Technology	FC / CO_2 Benefit	Implications for criteria pollutants
Advanced Combustion	Direct Injection	1.5%	PN emissions
	c-EGR	2 – 5%	Lower exh. T, lower NOx
	High CR (Atkinson cycle, c-EGR, DI, VVT)	10 – 14% [(1)]	
	Miller cycle (Turbocharged Atk., c-EGR)	12 – 20% [(1)]	
	Variable CR	10 – 15%	Early light-off, reduced PN
	Dyn. cylinder deactivation (+ VVL)	6 – 8%	↓ low load emissions, exh. T ↑
	Adv. turbocharging, e-boost	5%	
	2-stroke opp. piston (Diesel, GCI)	30 – 50%	Lower NOx, soot
	Dedicated-EGR	10%	Low NOx, HC traps
	Water Injection	5 – 7%	Low CO, NOx. High HC.
	Lean-burn gasoline	10 – 20%	NOx control
	HCCI w/ spark assist	20 – 30% [(4)]	Low soot, NOx. High HC, CO
	Low T Comb. (GDCI, RCCI)	> 35%	Low soot, NOx. High HC, CO
Electrification	Start-stop	2 – 5%	• Emissions with engine starts • Lower exh. temp. • Cold-start emissions • Reduction in idling emissions • High powered cold starts (PHEV)
	Mild (48V, other)	10 – 20%	
	Full	25 – 30%	
	Plug-in	65 – 75%	

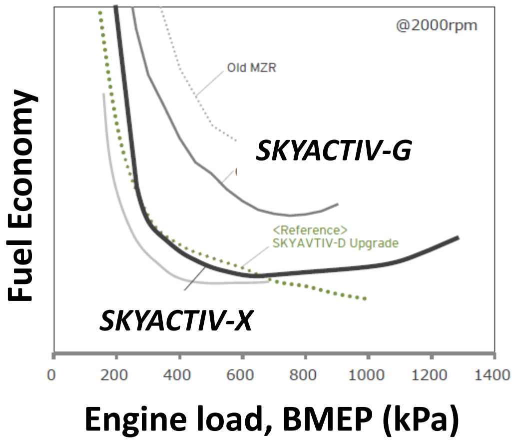
Mazda: Spark Controlled Compression Ignition

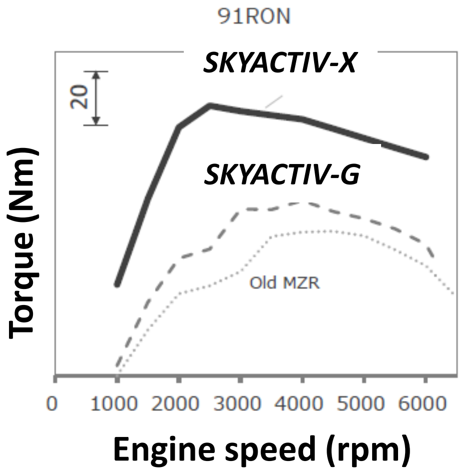
20 – 30% improvement in fuel consumption, 10% more torque



- Lean pre-mixture injected during intake stroke
- 2nd high P injection during compression stroke to create combustible mix around spark plug
- Spark to initiate combustion
- Expanding fireball creates push to further propagate combustion



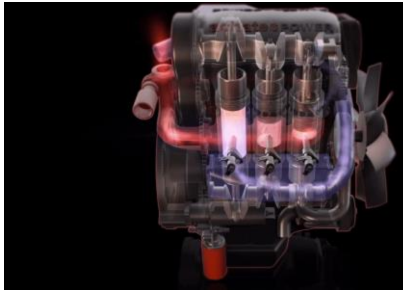


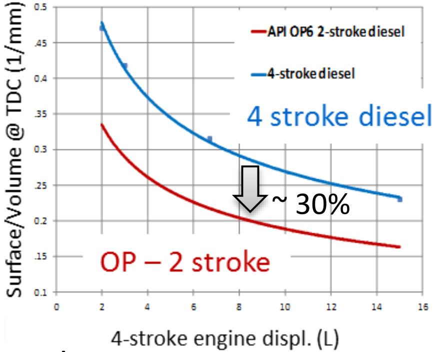


Opposed-piston 2-stroke engine

20 – 30% lower fuel consumption over conventional 4-stroke diesels

Achates, SAE 2016-01-1019, SAE LD Symp. 2017



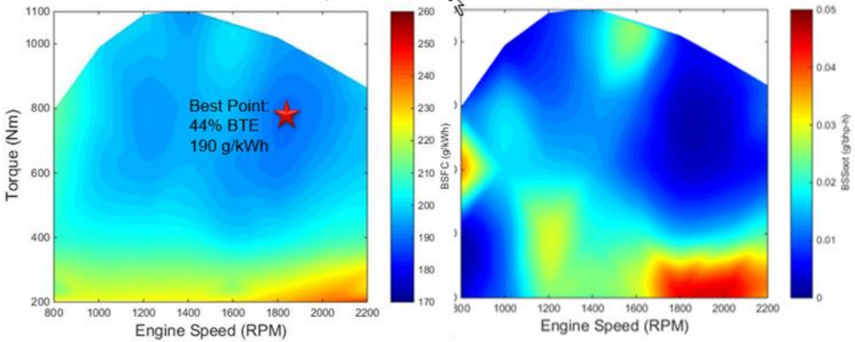


Lower surface/vol. → Reduced heat losses

Fuel spray perpendicular to piston travel, min. wall impingement

Light-duty multi-cylinder testing

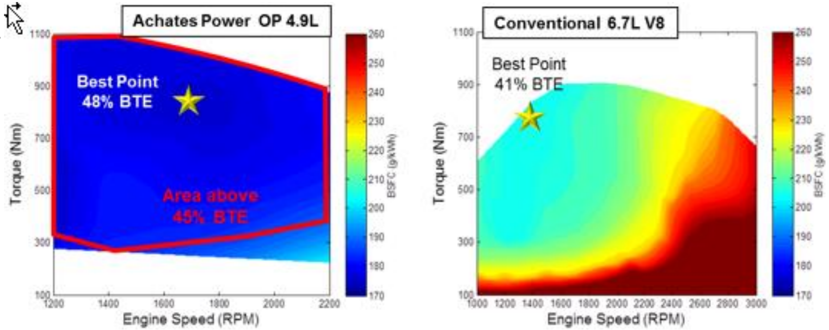
44% BTE, BSFC = 190 g/kWh   BS Soot = 14 mg/kWh



<u>Medium-duty 4.9L</u>

32% increase n BTE over 6.7L V8 4-stroke

20% increase in BTE over hot FTP, emissions meet US 2010



2.25L, in-line 3 cyl. (6 piston) LA4 drive cycle	Cummins Atlas	Achates 2.25L OP	
Fuel consumption (L/100 km)	8.81	6.89	*28%* ↓
NOx (g/km)	0.51	0.29	*42%* ↓
PM (g/km)	0.08	0.018	*74%* ↓

37 mpg on demo F-150 truck: 2.7L 3-cyl opp. piston

GDCI* approaching 200 g/kWh

Low exh. T → complex after-treatment for Tier3Bin30

*Gasoline direct inj. compression ign.

Delphi, SAE 2017 LD Symposium, Wisconsin ERC Symp. 2017

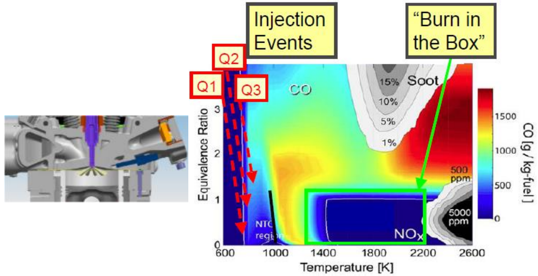
<u>Concept</u>:

"Burn in the box"

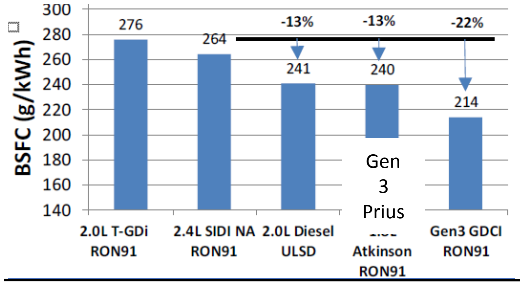
Partially pre-mixed CI, high CR (16:1)

Multiple late injections (350+ bar inj. P)

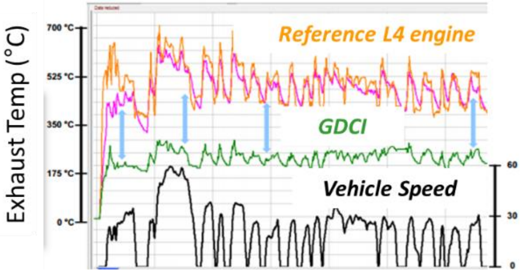
Heat release below Φ=1.2, T: 1200 - 2300 K



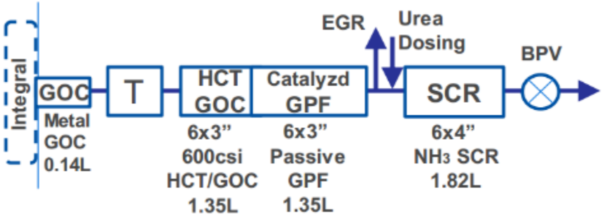
11% improvement over diesel / Atk.



Low-T comb. → ~150 – 300 ° C cooler exh.



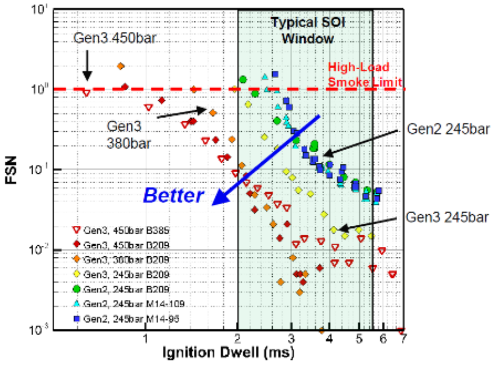
A/T: Pre-turbo cat., HC trap, passive GPF for off-cycle, SCR, EGR

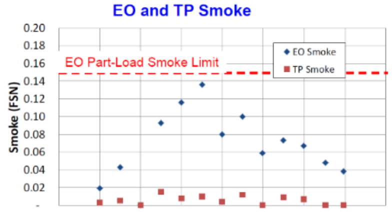


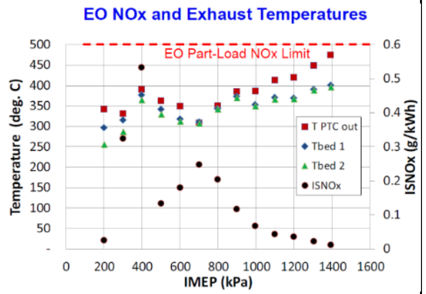
<u>Potential to meet Tier3 Bin30</u>

> 350 bar inj. P and wider spray angle

"wetless" injection for reduced particulates

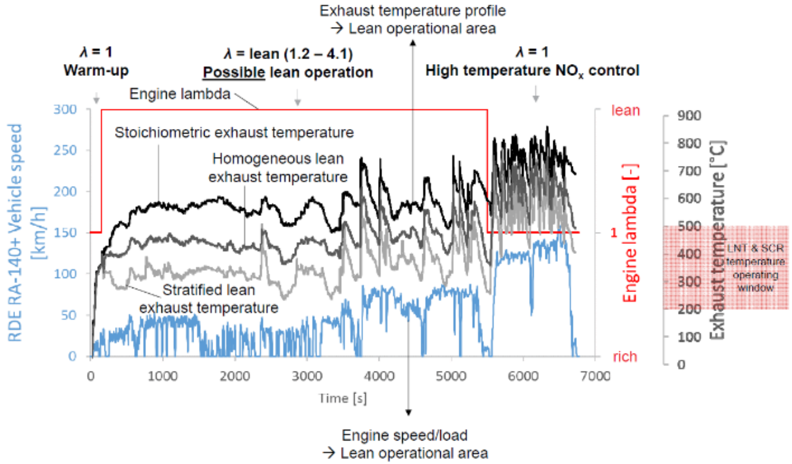






Path to > 10% CO_2 reduction, NOx < 40 mg/km
Lean gasoline engines with twin LNT

Ricardo, Wisconsin ERC Symp. 2017

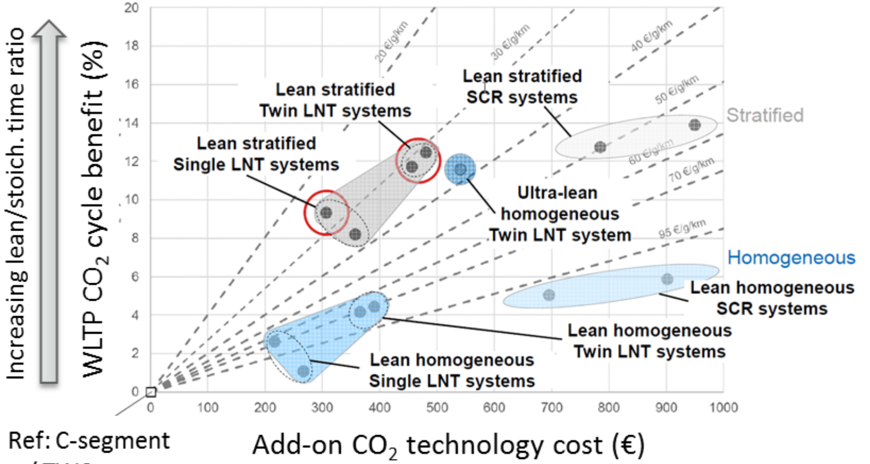


Target NOx *beyond Euro 6:* 40 mg/km, CF = 1.5

- Lean stratified combustion can deliver > 10% CO_2 reduction @ 30 €/(g/km-CO_2)
- LNT approach more cost-effective than SCR
- Meeting US N_2O regulations a challenge

Various A/T systems simulated on certification test cycles & RDE

CC	uF
TWC	GPF
TWLNT	GPF
TWC	GPF + LNT
TWLNT	GPF + LNT
TWLNT	GPF + LNT + pSCR
TWC	GPF + aSCR
TWLNT	GPF + aSCR

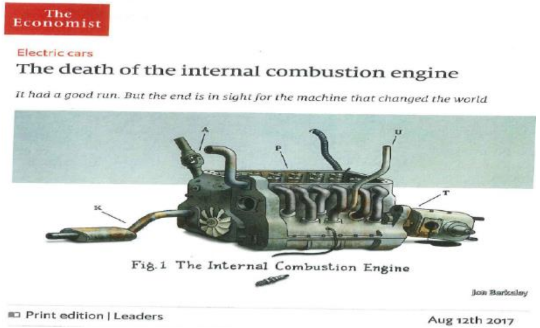


Ref: C-segment w/ TWC

LEAN-S – Engine add-on costs €90 (piezo injectors)
LEAN-H (λ = 2) – Engine add-on costs €150 (Advanced ignition system)
aSCR w/o AdBlue consumption incl. to FC benefit

Outlook on electrification is still mixed

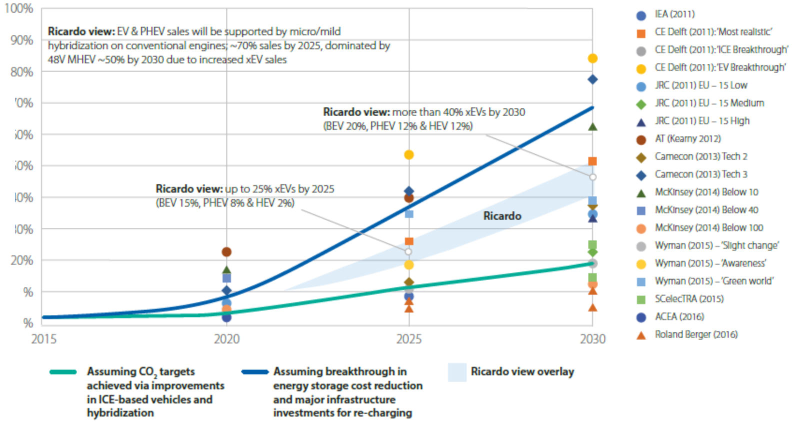
Mild hybrids expected to gain share. Pure EVs driven by mandates. Rapid improvements in battery costs and infrastructure happening.



"The reports of my death are greatly exaggerated" – Mark Twain

BEV + PHEV + Hybrids EU : Est. from < 20% to > 60% in 2030

RicardoAnalysis



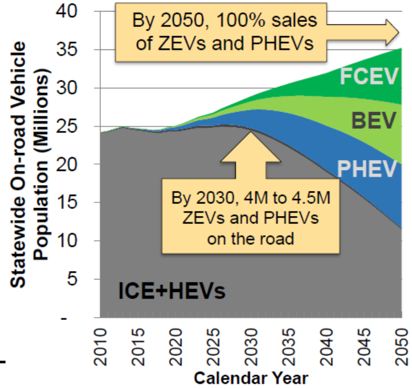
Electrified ≠ Pure EV

Propulsion Design		ICE	ICE S/S	Mild Hybrid	Full Hybrid: Conventional Full Hybrid	Full Hybrid: PHEV (Plug-in Hybrid)	(B)EV	FCV
System Design		E	E M B	E M B	E M B	E M B	M B	M FC
System Definition	Engine	✓	✓	✓	✓	✓		
	Motor		✓	✓	✓	✓	✓	✓
	Stop/Start		✓	✓	✓	✓		
	Propel Vehicle	Engine	Engine	Engine	Engine and/or Motor	Engine and/or Motor	Motor	Motor
	External Charging					✓	✓	✓
Technology / features			Stop/start	48V, BAS, IMA	Series/parallel Atkinson cycle	Charge depleting mode Larger batteries		

California: 100% BEV, PHEV, FCEV by 2050

CALIFORNIA AIR RESOURCES BOARD

SAE Govt. Industry Mtg. 2018



Electric Vehicle Perspectives

The mixed signals – Large obstacles to BEVs, but OEMs are spending big. How can this be explained?

On one hand, BEVs have huge obstacles

Expensive solution to climate change

Conservative customers and expense

Major infrastructure changes

Large political barriers - $3T car and fuel industry that is generally conservative

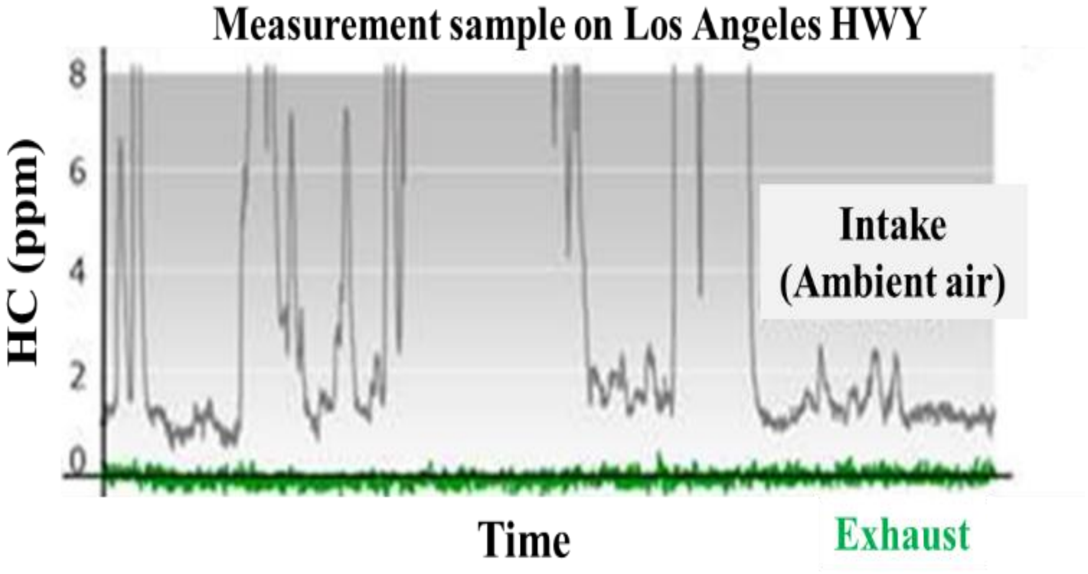
On the other hand, OEMs are making big investments

They are shifting resources from conventional to electric vehicles

They know their market, so why are they cannibalizing a known market for something with so much risk and such a long term payback?

Hypothesis: Institutional investors are moving money into PEVs, anchored by the certainties of climate change and subsequent mandates. OEMs need to adapt. “Build them and customers will come.”

The prospect of NEVs – Negative Emission Vehicles



1999 vehicle designed for 1/10 of ULEV: 4 mg/mi NMOG (non-methane organic gas) and 20 mg/mi NOx, or roughly SULEV

Honda, ICEV, Hokkaido, 8/17

Thank you

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